# SHOCK VEINS IN METEORITES: WHAT THEY TELL US ABOUT SHOCK CONDITIONS.

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**Introduction:** The goal of classifying the shock metamorphic features in meteorites is to estimate the corresponding shock pressure conditions [1]. However, the temperature variability of shock metamorphism is equally important and can result in diverse shock features in samples with equilibrated pressures. Shock-melt veins and melt pockets correspond to the highest temperatures in shock meteorites and they are the location of high-pressure (HP) minerals [2]. The usefulness of shock veins for interpreting shock conditions is debated. Stoeffler et al [3] suggest that shock veins do not provide useful estimates of shock pressure because they represent large deviations from average shock effects. However, these features provide an important mineralogical and chemical record of shock history [4]. Fritz et al. [5] claim that shock veins and HP minerals only record peak shock pressure in the isobaric zone for low-velocity (~ 2km/s) impacts, such as that recorded in L chondrites. Although other shocked materials may not sample the isobaric zone, their crystallization history is still useful for understanding the shock history. Here we calculate shock-temperatures and quench paths to semi-quantitatively evaluate the relationship between shock-melt crystallization and shock pressure.

**Shock Temperatures and Shock-Melt Quench:** Shock temperatures for a variety of rocks were calculated using the integral approximation along their Hugoniots [6]. The release *P-V-T* correlations are constructed by assuming an isentropic release adiabat and using a Mie-Grüneisen EOS. The bulk shock temperature of an L chondrite remains ~ 1000° cooler than the solidus up to 50 GPa. Shock-melt veins and pockets represent local temperature peaks that are caused by pore collapse, shear heating and complex peak-pressure variations during compression. For melting to occur during shock, these hot zones must reach temperatures in excess of 2200 K at 20 GPa and nearly 3000 K at 50 GPa. Small volumes of melt, as in S6 shock veins, are quenched primarily by heat transfer to the relatively cool surrounding rock. Adiabatic decompression of a shock melt, without heat transfer to a cooler host rock, would not crystallize HP minerals, but would result in crystallization at ambient pressure.

**Constraints from Shock Vein Assemblages:** Shock stage S6 is restricted to melt zones in chondrites with bulk shock stages of S4 to S5 [1]. S6 shock veins in L chondrites generally contain crystallization assemblages of majoritic garnet with oxide, ringwoodite or wadsleyite. Samples, such as Tenham and Acfer 004, have higher pressure assemblages with bridgmanite and akimotoite. Many of these shock veins have assemblages that reflect a relatively narrow range of crystallization pressure, suggesting crystallization in the isobaric zone of the impact [5]. However, L6 impact-melt rocks, such as Chico and NWA 091, which show pervasive melting and darkening but no high-pressure minerals, indicate shock pressures higher than S6. Shocked Martian meteorites show a distinctly different crystallization history. Some have olivine disproportionation reactions that indicate higher pressures than those recorded in L6 chondrites. In addition, the shock-melt quench products vary significantly depending on the size of the melt zone. In Tissint, for example [7], µm-scale veins crystallized high-pressure assemblages whereas, mm-scale melt pockets remained liquid until after pressure release. This is because the shock duration, from a relatively small impactor, was shorter than the cooling time for the thick veins. The Martian augite basalt, NWA 8159 [8], has mm-scale shock veins contain majoritic garnets throughout, indicating a narrow range of crystallization pressure and a relatively long shock pulse. The crystallization assemblage preserved in shock meteorite is dependent on both the shock pressure and the local thermal history of the sample. Calculated shock-temperature heterogeneities and resulting melt-quench paths constrain the possible relationships between peak shock pressure and crystallization pressure in shocked meteorites. We show that detailed characterization of shock melt can help construct a comprehensive *P-T* history of shock, including the peak shock pressure. Shock veins in meteorites should not be ignored.

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